# Restoration of Habitats Impacted by Oil Spills

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CHAPTER 6

# Fisheries Resource Impacts From Spills of Oil or Hazardous Substances

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## INTRODUCTION

Fisheries is the traditional designation for exploitable aquatic organisms (plants and animals) in fresh, estuarine, and marine waters. Exploitation connotes utilization or economic value, but, in terms of species, fisheries also include organisms of aesthetic or genetic preservation value (e.g., endangered species) as well as commercial species. Major elements of life histories, food webs, habitats, and migration routes comprise fisheries ecology. These elements are also involved in fisheries resource assessment. Fisheries resource assessment methods typically apply representative parameters to models in order to estimate population structure, fecundity, and calculated levels of sustainable catch, harvest, renewal, or production. All habitats discussed in this book, with perhaps the exception of the

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tundra, are specific fisheries resources in considering contamination effects of spillages.

Oil pollution is a potential impact to fisheries resources for three reasons (Wardley-Smith 1976): (1) a direct (lethal or sublethal) effect to fisheries stocks may occur, (2) oil may render the fisheries products unacceptable to the consumer, and (3) fishing operations may be directly affected by the presence of oil. These reasons may be extended to other hazardous or toxic materials. Examples have been documented for each of these reasons. High mortalities occurred among oysters in the estuaries of Brittany, France during the 1978 *Amoco Cadiz* spill. Oysters and other fisheries resources elsewhere have acquired hydrocarbon taint from spills or seepages. The vast areas covered by oil released from the *Ixtoc I* well blowout near Campeche, Gulf of Mexico in 1979 caused shrimpers and other fishermen to change location of their operations.

In the brief review that follows, we use many of the common terms of environmental science with these specific meanings:

*Impacts* are effects of contamination upon habitat, food and nutrition, physiology, cell and organ function or structure, growth and metabolism, reproduction, behavior, species life history success or composition and/or population or fishery yield changes.

*Damage* represents the economic cost to mitigate or repair an impacted resource to an acceptable level.

*Recovery* is the process of species returning to normal population levels after an impact.

*Restoration* represents management steps designed to accelerate recovery or repair.

*Susceptibility* is the lowered resistance to pathogenicity, toxicity, or death in response to contamination.

*Vulnerability* is a predictable level of a negative impact response to an event.

*Sensitivity* is a scale of relative vulnerability.

## FISHERIES ASSESSMENT CONSIDERATIONS

A key question in spillages in an aquatic environment is: what fisheries impacts may occur? This question immediately brings forth all the interactions and complexities involved in ecosystem processes.

Ecological considerations include: kinds of sites and habitats involved, species of organisms present, commercially utilized species, life history stage(s) exposed to spill impact, migration patterns, food or nutrition, and nursery areas.

Characteristics of the spill include: type of chemical(s) released, amount of contaminant involved, rate of release to environment, time of release, duration of exposure of effected areas to chemical constituents, measures for retaining or removing contaminants, and use of counteracting or dispersing agents.



Each spill event has its own unique set of "spill characteristics" in terms of location, volume and type, season of the year, physical/hydrological characteristics (salinity range, tidal range, and wave environment), proximity to fisheries resources, and weathering rates of the agent. In turn, each of the preceding factors has different degrees of interdependency and interaction that combine to define the characteristics of the spill event. For example, at the *Amoco Cadiz*, the season of the year (March, which influenced both spill onshore movement and oil weathering rates) and close proximity of the wreck site to shore interacted to produce a catastrophic effect on certain fisheries resources, due both to the toxic nature of the oil and to smothering effects from the large volumes of oil discharged. At the other end of the spectrum was the *Ixtoc I* well blowout in the Gulf of Mexico. In this case, the rapid summertime weathering rates, together with the great distance of the spill site from the Texas coast, resulted in the oiling of Texas beaches and entrances of some tidal inlets with a heavily weathered, practically nontoxic oil product. This petroleum did not cause dramatic effects on fisheries resources along the Texas coast, although there were fragmentary reports of some impacts to shellfish in Mexican coastal lagoons closer to the spill site.

The nature of the contaminating agent, the concentration and chemical characteristics of the spilled petroleum hydrocarbons (PHC), and the duration and type of exposure are the most important extrinsic factors in determining effects upon fisheries. In terms of chemical characteristics, the worst case would be an incident (e.g., *Amoco Cadiz*) in which a large volume of a highly toxic product completely inundates and smothers organisms for an extended time (days), causing both exposure to toxic chemicals and anoxic conditions. Such conditions generally result in mass mortalities among sedentary shellfish, particularly clams, oysters, mussels, or scallops. At the other extreme would be the situation in which only a small quantity of virtually nontoxic petroleum product (e.g., asphalt) is spilled.

Neff et al. (1976a) reported that petroleum products vary tremendously in their toxicities to marine organisms, but the following generalizations can be made:

(1) refined products are more toxic than crude oils,
(2) the relative toxicity of an oil is generally related to the content of aromatic hydrocarbons,
(3) the toxicity of aromatic hydrocarbons increases with increasing molecular size from benzene to phenanthrene, although the four- and five-ring aromatics are not acutely toxic,
(4) the alkyl-substituted analogues of these compounds are more toxic than the parent molecule, and
(5) differences in aqueous solubility and bioconcentration potential appear to depend on relationships between chemical structure and biological activity.

Additional consideration must be given to high molecular weight fractions of PHC (e.g., benzo(a)pyrene) that are generally considered very low in acute toxicity potential due to their low solubility, but are very high in tumorigenic or carcinogenic potential (Brown et al. 1979; Couch et al. 1979; Mix et al. 1979). These high molecular weight (four- and five-ring) compounds need careful consideration since potential exists for food web transfer from fisheries to consumer, which implies a potential change from resource impact to human health risk.

The fisheries resource evaluator is expected to assimilate and integrate these basic facts of structure and function and to design, on the spot, a strategy for assessment, prediction of possible effects, and mitigation of damages. The ultimate decisions whether to undertake restoration of critical habitats will depend upon the initial circumstances and success of protection efforts, along with the care taken to assimilate data into the effects/damage assessment effort. Accomplishment of this function requires consideration of effects that range from cellular dysfunction, to physiological effects, nutritional/food effects, organism malfunction (e.g., loss of reproduction), through effects upon life history stage, year-class, or even population structure. From this very broad array of considerations, the evaluator is expected to derive a synthesis and measurement of the impacts, possibly including damage.

Population effects on fisheries and aquatic species do occur, but most often are attributed to overexploitation, habitat destruction, effects of a habitat invader (e.g., lamprey), or effects of bioaccumulation of persistent contaminants, such as metals or pesticides (e.g., fish, birds, mammals). The very dynamic physical and chemical features of petroleum in natural systems coupled with the varied biological aspects mentioned above have resulted in few, if any, published accounts that clearly correlate oil spills with effects upon finfish at the population level. Sessile shellfish or nonmotile species provide the most frequently reported adverse impact correlations with PHC spills. Additionally, research reports do demonstrate interaction between contaminant and ecological and physiological parameters during exposure.

Sedentary bivalve shellfish species are capable of only passive avoidance, which involves closing the valves and switching to anaerobic metabolic pathways to cope with the stress of contaminant exposure. The duration of this passive avoidance is temperature dependent—longer periods of avoidance behavior being observed in the winter rather than other seasons. Once exposure has occurred, the organism readily begins to bioconcentrate PHC into body tissues due to the lipophilic nature of most PHC compounds. PHC and similar compounds readily penetrate the lipoprotein cell membrane complex in most organisms via direct diffusion; other mechanisms, such as active transport, endocytosis, and filtration, may also be involved in varying degrees. In many species of shellfish, lipid concentrations vary with seasonal changes of biochemical constituents normally associated with spawning activities; thus, it is important to understand which seasons of the year are potentially maximum PHC uptake times simply in terms of the maximal internal lipid or glycogen substrate availability. Oysters (*Crassostrea virginica*), for example, contain maximal glycogen concentration during



the spring (Galtsoff 1964) and exhibit the highest rate of PHC uptake occurring at this time. Stegeman and Teal (1973) exposed oysters to water soluble fractions of #2 fuel oil and demonstrated highest uptake rates in oysters that had high lipid content. Neff et al. (1976a) reported similar results in oysters exposed to #2 fuel oil; the uptake of naphthalene and methylnaphthalene accounted for 90% of the total PHC uptake. Following return to clean seawater, naphthalene was rapidly depurated within 24 hours while methylnaphthalene took 672 hours for nearly complete depuration. Neff et al. (1976a) reported that in acute exposure of clams, *Rangia cuneata*, phenanthrene was most toxic due to its rapid bioconcentration and slow depuration kinetics that favor accumulations in tissues. Rapid bioconcentration and depuration rates of naphthalene made it less toxic than the phenanthrene. The authors concluded that compounds such as naphthalene, phenanthrene, and benzene, which have rapid bioconcentration kinetics, would be responsible for most acute toxicity while compounds with slow depuration kinetics would be more responsible for chronic toxicity in most marine organisms tested. In poikilothermic or metabolically conforming organisms (i.e., most shellfish species) it is important to remember that both bioconcentration and depuration rates are directly temperature and physiologically dependent.

Neff et al. (1976b) also reported that in 24-hour exposures of *Rangia cuneata* to various fractions of a #2 fuel oil, bioconcentration factors ranged from 2.3 for naphthalene to 26.7 for trimethylnaphthalene. Following exposure, clams were depurated for 24 hours in clean seawater that resulted in significant release of naphthalene (79%), whereas other substituted naphthalenes were released at a slower rate (32 to 51%). These data illustrate the importance of the degree of chemical substitution in determining uptake/depuration kinetics (i.e., the nature of the PHC).

Anderson (1979) reported that bivalve mollusks bioconcentrated PHC from the water in both the dissolved and particulate phases. Additionally, differences in the uptake of n-alkane fractions of PHC by bivalves were related to the presence or absence of dispersed oil droplets or oil adsorbed to particles. When only water soluble PHCs were used, the uptake of n-alkanes was relatively small and depuration was very rapid, due to possible incorporation into feces or pseudofeces.

Bioconcentration of PHC in bivalves tends to be slow but constant, whereas uptake in shrimp, crabs, and other crustaceans appears to be very rapid and reaches maximum tissue concentrations within a few hours (Anderson 1979). Faster bioconcentration in crustaceans is probably related to differences in integument that favors increased PHC absorption related to the lipoidal nature of the epicuticle that facilitates lipophilic compound uptake.

The life history stage of the species is highly relevant to its susceptibility to adverse effects. It is generally assumed that the year-class strength or recruitment of many species is determined by survival through the larval stages (Hunter 1976) and this is termed the critical period (Hjort 1914). Although early life history stages are typically the most sensitive, only a few data reports document effects of oil spills upon finfish recruitment. In the massive spill from *Amoco Cadiz*

Desaunay (1981) and Miossec (1981) report disappearance of the 1978 year-class of both sole (*Solea vulgaris*) and plaice (*Pleuronectes platessa*) from contaminated areas of northern Brittany. Miossec (1981) further detailed changes in gonadal indices, and Conan and Friha (1981) and Conan (1982) reported abnormally reduced growth rates in fishes from contaminated areas. These examples show both population and physiological stress responses resulting from petroleum spillage. Although stress responses among organisms occur frequently and do not necessarily affect species survival or change in population structure, these responses do raise concern about species susceptibility to other environmental pressures and pathogenicity (Sindermann 1982). Interpretation of these sorts of evidence demonstrates the need for forensic approaches to environmental assessment. That is to say, simple correlations do not fully represent the dimensions of important spill effects, and coordinated studies must be carefully evaluated and interpreted to discern false from real PHC impacts. The *Amoco Cadiz* fisheries data are somewhat easier to interpret in this context inasmuch as the 1979 fisheries species (plaice, sole, and mullet) year-class subsequently returned and certain 1978 physiological stress manifestations did not recur during 1979 or 1980 (Conan 1982). Haensly et al. (1982) and Neff and Haensly (1982) report that biochemical and histopathological effects persisted and progressed in plaice, but not in oysters of the *abers;* this is an unusual observation and needs more careful evaluation.

Among many boreal or Arctic fisheries species, an individual year-class may represent a significant or major part of the fisheries harvest. In terms of recruitment then, rates of reproductive and larval success and presence of suitable nursery areas are highly critical components for each year-class. Therefore, these factors become the focus of concern in preparation for or response to contamination events. For threatened or endangered species, such as marine turtles, some mammals, and birds, these components are of highest concern for perpetuation of the species. Long-term impacts on such species are a continued concern.

## PREPARATIONS FOR SPILL EVENTS

Prespill contingency plans have been established for many areas in close proximity to major extraction, transfer, and bulk transport installations where there is potential for spills of contaminants such as petroleum (Cox 1977). Governmental agencies and institutions with expertise have participated in regional planning conferences and a few oil spill simulation exercises during 1979–80 (Lefcourt 1980). In those situations of which we are aware, focus has been oriented more to identification of specific people for response roles than to broad issues, such as fisheries responses. As a result, during an actual spill event people with certain kinds of background information are brought in, often uninitiated with the structure of the overall spill-response organization or with the specific and appropriate "before" and "during" event data needs. This kind of situation was magnified in the 1979 *Ixtoc I* blowout in the Gulf of Mexico (Hooper 1981).



However, the ensuing problems experienced by scientists and decision makers during the *Ixtoc I* event have resulted in several concise plans for future reference. Reed (1981) and others have developed a fisheries impact model for ecosystem component relations that can serve as a worthwhile starting point as well as a reference system when diverse groups are brought together during emergency spill responses.

## PROTECTION OF IDENTIFIED FISHERIES

Strategies for evaluating impact before, during, and after a spill will depend on the location and type of spill and the life history stage impacted (see previous sections). For marine fisheries, location can be conveniently separated into open ocean, estuarine and nearshore, and benthic (including coral) habitats. It is not generally feasible to "protect" large areas of open ocean from oil spills. Special care must be taken, however, before application of sinking or dispersing agents since data are not available on how petroleum dispersant mixtures will affect open water organisms as the new solutions of PHC are spread into the water column.

### Open Ocean

The eggs and larvae of many marine species are pelagic and the spawning areas are large. Therefore, in order to impact fisheries at this stage of development, a contamination spill would have to be very large, coincide with spawning, and contain water soluble toxic components that remain present for long periods. This occurrence is not probable, but could occur in certain cases where spawning grounds are specifically bounded or restricted. Significant numbers of adult fish are not likely to be killed by oil spilled in unbounded areas of open ocean.

### Estuarine and Nearshore

Many fisheries organisms (fishes, scallops, crustaceans, birds, turtles, mammals) utilize estuarine and nearshore waters as nursery areas. Bounded shallow inshore waters are areas where fisheries vulnerability is greatest. Since year-class strength of many fishes is probably fixed at or soon after arrival into the nursery area, any increase above natural mortality due to contamination or pollution can have an effect on the catch of that fishery. Sessile species or forms with low motility are more susceptible to inshore spillage events, particularly when extended duration of exposure occurs. The habitats featured in the other chapters of this publication reflect the emphasis ecologists and environmentalists place on inshore habitat types. The nature of the spill and subsequent events further interact to affect the final outcome. For example, *Ixtoc I* petroleum tended to disperse widely over the western Gulf of Mexico, staying in open waters much of the time, but the *Funiwa V* blowout off the Niger River delta, West Africa decimated 800 acres of mangrove and coastal habitats (Idoniboye-obu 1980). In the *Funiwa* event, protection measures were not taken, but the habitat was particularly difficult to protect under the circumstances that existed.

Exposure of economically important species of shellfish to PHC can result in a variety of lethal and sublethal responses. The exact nature of these responses varies depending upon such extrinsic factors as concentration and chemical type of petroleum product spilled, duration of exposure (continuous vs intermittent, acute vs chronic), actual bioavailability, and season of the year. Intrinsic factors that affect species responses include type and stage in life cycle of species impacted, mode of feeding (filter feeders vs scavengers), ability or inability to metabolize and detoxify PHC, and successful avoidance behavior (passive vs active).

Pelagic or motile epifaunal shellfish, such as crabs, lobsters, shrimps, and scallops, are capable of active avoidance of spilled petroleum products, whereas sedentary organisms, such as oysters, clams, and mussels, are only passively able to avoid exposure by closing their valves and utilizing anaerobic metabolic pathways. Thus, sedentary forms can be more susceptible to petroleum exposure and should be given particular consideration by environmental managers during formulation of mitigation strategies.

Impacts to shellfish populations can be lethal, yielding direct, easily measurable impacts on fisheries populations. Sublethal or more subtle impacts occur as altered physiological effects that reduce reproductive fitness or completely impair reproduction by changing metabolic pathway kinetic rates. Reduction or complete impairment of reproduction is sometimes equated with indirect lethality. However, measuring such impacts requires significant effort and extrapolation by scientists and is virtually impossible unless an adequate prespill data base exists with which one can reliably compare calculations of biochemical or pathological impact (Wolfe et al. 1981) or indirect physiological impacts (Bayne et al. 1982). Examples of such comparisons are rare for field assessments (Chassé and Guenole-Bouder 1982; Wells and Cowan 1982). Additional laboratory toxicity testing is desirable to confirm and corroborate field observations of oil induced impacts.

In terms of mitigation of impacts to shellfish resources, two basic approaches can be used. The first, more conventional approach is simply to protect the shellfish harvesting areas by one of the "fence off" techniques. The second, less conventional approach is either to harvest shellfish populations completely prior to contamination or to transfer manageable shellfish resources from areas of primary impact to safer areas. This approach requires a high degree of advanced warning and preplanning (not typical for oil spills) and sufficient manpower to relay organisms to refuge areas, given that such identified areas exist. If this second approach is considered in coastal areas, manpower resources (i.e., wildlife organizations, fishermen, and environmental groups) must be organized prior to any actual spill event so that they can be alerted and activated at the time of the spill.



## STRATEGIES FOR FISHERIES ASSESSMENT

Attempts have been made during a number of oil spills to obtain useful comparative assessment data. Echo sounding surveys (Nellbring et al. 1980) were used to compare herring and sprat schools before and after the *Tsesis* oil spill near Asko, Sweden in 1977. Active fisheries off the Brittany coast had not yet begun at the time of the wreck of the *Amoco Cadiz*. However, portions of the cultured oyster in threatened estuaries (*abers*) were trucked to protected bays. Data were summarized from previous years of harvests of algae, crab trapping, and fish and scallop trawling operations to prepare for comparisons to eventual oil spill effects. Shoreline surveys were conducted using well-organized teams of students to census intertidal organisms and to conduct "body counts" of seals, birds, fishes, invertebrates, and algae acutely impacted by the petroleum (Davis 1979; Conan 1982). In both the *Tsesis* and *Amoco Cadiz* spills, toxicity tests were conducted in attempts to assess potential effects on larval hatching. Extremely rough water conditions delayed some other techniques, such as in situ video surveys or extensive use of scuba divers, until some weeks after the wreck of the *Amoco Cadiz*. However, these techniques were applied as follow-up monitoring tools.

In the case of *Ixtoc I* blowout, active shrimping was under way at the time of the accident. International bureaucratic complications precluded effective or useful ecological sampling and assessment near the well site. Aerial overflight observations gave the generalized impression of fishermen avoiding the *Ixtoc I* spill area, but activity continued within the overall Gulf fishery. Floating oil took a few weeks to traverse the 600-mile distance from Campeche to Padre Island in Texas. As this sun degraded residue arrived on U.S. shores, it adhered to beach sands and consolidated into tar reefs or various sized submerged particles. Concern was raised regarding the unknown potential threat to nearshore shrimp stocks. A grid of offshore sampling stations was laid out (Sheridan, personal communication; Griffith 1980) to construct a map of the distribution of petroleum residue and associated organisms. The organisms sampled represented both bioindicators of benthic communities and commercial species. Samples were inventoried and subsampled for "voucher specimens" for any future need to determine body burdens of PHC. Petroleum residue was collected along with organisms in standard try-net shrimp trawls by the insertion of oil absorbent pads into the cod-end prior to each trawl haul. The absorbent pads and voucher specimens were placed in aluminum foil and frozen for future PHC analyses (Griffith 1980). The 130-station sampling grid was designed to sample at 15-, 30-, 60-, 120-, and 180-foot depths; 15-, 30-, and 60-foot stations spaced at 5-mile intervals and 120- and 180-foot stations spaced at 10-mile intervals along the coast from Brownsville to Matagorda, Texas. The grid was also designed to overlap transects established by Texas and Bureau of Land Management investigators, who had previously sampled sediments and infauna for ambient hydrocarbon levels. In addition, shipboard tests were run to detect oleophytic microbial organisms. Finally, bottom drifters were deployed to establish bottom water movements at each station.

This overall strategy produced bathymetric distribution of visual records of residue, set up a system for station associated currents and drift, and established a reference bank of voucher specimens for further PHC analyses. Such a strategy could be adapted elsewhere, utilizing available vessels, and should be repeated to monitor any "hot spots" that occur or whenever seasonal information may be needed. Furthermore, this strategy allows subsurface aquatic habitats to be sampled in a manner comparable to the shoreline and shallow coastal habitats, which are easier to visit and sample (Gundlach and Hayes 1978).

## OTHER OPTIONS FOR ASSESSMENT OF RECOVERY OF FISHERIES

In a spill sparsely documented in the English language literature, oil released into the Seto Sea of Japan interacted directly with valuable and active fisheries (Hiyama 1979). The Japanese strategy used traditional nonadversary approaches, wherein fishermen were activated and utilized in the assessment/sampling system. The government adopted the role of market, and fishing was encouraged to continue without interruption. However, catches were vigorously monitored, and all contaminated species were shunted away from human consumption. The fishing effort became, therefore, both a sampling and monitoring tool and may have assisted in removal and mitigation of contaminant levels. The expenses incurred became realistic costs for economic damage assessment calculations. The response to this accident was focused upon restriction of economic loss to the victims and rapid recovery of the ecosystem, rather than protracted legal and punitive actions. Response costs were subsidized by the government initially and thereafter assessed through negotiated settlement with the spiller. Recovery of the resource was managed to enable return to previous harvest levels as quickly as possible, using scientific expertise and mariculturists as mutual consultant/managers.

All contamination situations cannot be so easily restored. In the *abers* of Brittany, continued long-term release of *Amoco Cadiz* hydrocarbons from sediments rendered many former oyster beds unusable for rearing consumer products (Balouet and Poder 1981; Friocourt et al. 1981; Maurin 1981). Considerable cost is being expended to accomplish recovery of this fishery through both culture husbandry and habitat restoration.

## RESTORATION

In other fisheries (e.g., sea turtles or seals) whole populations are very vulnerable during concentrations at nesting sites and through the early life history stages (a 2- to 3-year duration). Here, susceptibility and vulnerability incorporate rookery nesting and nursery sites together with critical life history stages. In such cases, actual restocking by hatchery reared organisms after site restoration (or at alternate sites) would appear to be a principal option for population restoration



response. A concerted effort on behalf of sea turtle species is currently under way.

Restoration techniques have been used previously in fisheries in ponds, lakes, or rivers. Examples include hydroelectric dam fish ladders, removal of massive pollutant sources, and the control of sea lampreys. Such techniques become necessary at sites that have suffered long or extensive damage ranging from site/habitat destruction, loss of food web species, or impingement of migration routes. Decisions whether to adopt a "hands-off" recovery strategy vs a managed restoration represent value judgments based upon extent of damage to fishery structure or function, or both, coupled with the value of the resources involved (Table 6.1). Restoration or managed enhancement seems feasible when natural recovery rates are judged too slow to reestablish the desired species or ecosystem. In the case of endangered species, we most often find precedent for restoration of specific populations. This level of action may be pursued where the extent of impact is great, as in the *abers* of Brittany, or where massive vegetation loss leads to irreversible erosion of habitat, as in Isle Grande, Brittany after *Amoco Cadiz* (Seneca and Broome 1982). Such considerations will arise in the future should restoration under the Superfund Act be pursued.

If other strategies for population recovery fail, it is possible to reseed suitable shellfish growing areas with naturally set spat from clean substrate material or from hatchery reared spat or juvenile forms introduced directly into the environment. Such reseeding operations are expensive, often long-term efforts, and not always successful. However, if reproducing populations are successfully reestablished in an impacted area, the area should recover, providing residual contamination does not impair normal physiology and development and that adequate niche and food resources are available there.

One consideration that may be made by environmental managers after a spill has occurred is establishment of specific hatcheries for culture and rearing of appropriate species for reseeding. If pollution remains high in the impacted areas, it may be desirable to reseed alternate areas in order to replace the lost habitat and shellfish populations. This subsidized stocking approach could provide a mechanism for return to desired catch levels.

In southeastern U.S. coastal areas, a potential approach would be to dredge areas adjacent to tidal creeks to create new shellfish harvesting habitats comparable to the area impacted by the spill. This proxy substitution approach would provide a permanent replacement for an impacted habitat that had suffered irreparable damage. Such an approach should only require shellfish subsidies during the first 2 or 3 years or until harvestable populations are reestablished.

## RECOMMENDATIONS FOR FISHERIES RESEARCH AND MANAGEMENT CONSIDERATION

In the broad area of fisheries research, current focus upon population assessment and sustained yields is not totally appropriate for assessment of impacts and

**Table 6.1** Priorities for Fisheries Resource Decisions for Spill Response

| | Habitat | | | | Organisms | | |
|---|---|---|---|---|---|---|---|
| *Strategy* | *Offshore Pelagic* | *Offshore Benthic* | *Nearshore Estuarine* | *Coral* | *Endangered Species and Marine Mammals* | *Shellfish* | *Finfish* |
| Protection required | No | No | Yes | Yes | Yes | Yes | No |
| Cleanup required or possible | No | No | Maybe | Maybe | Yes | Yes | No |
| Restoration needed or possible | No | No | Maybe | Maybe | Yes | Maybe | Maybe |
| Recovery expected time frame | Yes | Yes | Maybe | Maybe | Maybe | Yes | Yes |
| Research needed | Yes | Yes | Yes | Yes | Yes | Yes | Yes |



follow-up from contaminant spills (Beverton 1982). Some areas that typically are ignored in fisheries assessments but that must be incorporated into realistic spill impact/assessments include:

(1) relation of species or population stress to actual impact,
(2) susceptibility of important species to contamination impacts,
(3) integration of toxicity data with field assessment/validation studies,
(4) use of agents that disperse, sink, or otherwise allow entry of the PHC into the water column or onto substrates where earlier life history stages occur,
(5) determination of recovery times of:
    (a) oiled habitats allowed to rest untreated, and
    (b) oiled habitats that are treated or cleaned to accomplish realistic strategies for restorations of habitats,
(6) techniques (including pathobiological) that reveal chronic sublethal effects upon fisheries species, such as susceptibility to pathogens or cellular dysfunction, lesions, tumors, neoplasia, reproductive anomalies, or other adverse effects (Sindermann 1982),
(7) continued asssessment efforts after the initial spill to evaluate projections and effectiveness of measures taken.

Fisheries sampling and research programs should incorporate a component for application to massive contaminant release(s).

Fisheries management plans should be modified to include contingencies for active use of fishermen, where appropriate, during spill sampling and in post-spill assessment and monitoring of recovery progress. Focus should be placed upon review of past spill assessments, incorporating appropriate research and monitoring to determine chronic or pathobiological responses of fisheries species or their supporting food web species.

From the examples provided by petroleum spills, which tend to be rapid rate events, we must further derive strategies for other contaminants that exhibit effects in chronic and more subtle ways. Effective integration and interpretation of scientific research and economic assessments to achieve successful protection and management of living resources exposed to agents remain a formidable challenge to all ecosystems managers, especially those who specialize in aquatic environments.

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